# METHOD AND APPARATUS FOR INSTRUMENT CALIBRATION CONTROL

## BACKGROUND

In numerous environments, electronic instruments and systems are used for the measurement of parameters important in that environment. For example in developmental laboratories and in manufacturing facilities, electronic instruments can be used to measure the thicknesses of parts, machine alignments, signal frequencies, dielectric constants, optical parameters, etc. To ensure that the values obtained in these measurements are accurate, the instruments involved must be periodically calibrated.

For some companies, the accurate calibration of their instruments is so important that they employ a calibration system in which the calibration history of each instrument is centrally maintained. Further, the accuracy of the standards used in the calibration of the instruments are traceable to the National Institute of Standards and Technology. In some cases, the traceable standards used are maintained by the company's standards laboratory. To be National Institute of Standards and Technology traceable, there must be an unbroken chain of measurements from the instrument calibration to standards which are maintained by the National Institute of Standards and Technology.

Based on the calibration history of a particular instrument, the instrument may be physically removed from service, which could be a production floor, for calibration. Depending upon the timing of the calibration and the amount of time needed to perform the calibration, the removal of a particular instrument from active service may prevent the manufacturing operation from making a needed measurement or measurements in a timely manner. The lack of such a measurement or measurements may result in the manufacturing process drifting out of specification or alternatively a production line may be temporarily shut down until such calibration is completed.

Different companies maintain calibration programs with various degrees of success. At one end of the spectrum, some companies maintain very rigid, accurate

calibration programs which are centrally controlled. When a particular instrument should be calibrated may be determined from a computer database. In other cases, a removable sticker which lists the calibration due date may be placed on the instrument. At the other extreme, other companies may seldom, if ever, perform calibrations. Even when calibrations are performed, it may be that they are completed against standards that are not traceable to the National Institute of Standards and Technology. Some companies may initiate comprehensive calibration programs but, with time, become overwhelmed by the complexity of maintaining the timely calibration of what may number in the hundreds of instruments.

## SUMMARY

In a representative embodiment, a method includes determining instrument calibration status, wherein the determination is made automatically by the instrument examining calibration history data stored by the instrument. When instrument calibration is past due, a user is notified that the calibration is past due, wherein the notification is initiated automatically by the instrument. The user can decide to make the measurement with the out-of-calibration instrument. Otherwise, the instrument is removed from measurement service, the instrument is calibrated, the calibration history stored by the instrument is updated to reflect a new time that a new calibration is due, and the instrument is returned to measurement service. Additionally, when the instrument calibration due date is approaching, a user may be notified of that fact automatically by the instrument. Also described are techniques for calibrating only those signal paths, subsystems, and ranges are actually being used or may potentially be used. In addition, if the user does decide to make a measurement while the instrument is out of calibration, he may be informed of the measurement uncertainty in making such a measurement.

Other aspects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings provide visual representations which will be used to more fully describe embodiments of the invention and can be used by those skilled in the art to better understand those embodiments and their inherent advantages. In these drawings, like reference numerals identify corresponding elements.

Figure 1 is a drawing of an instrument system as described in various representative embodiments consistent with the teachings of the invention.

Figure 2 is a flow chart of a method for controlling the calibration of the instrument as described in various representative embodiments consistent with the teachings of the invention.

Figure 3 is a flow chart of another method for controlling the calibration of the instrument system as described in various representative embodiments consistent with the teachings of the invention.

Figure 4 is a drawing of a data structure for a record for calibration information for the instrument system as described in various representative embodiments consistent with the teachings of the invention.

Figure 5 is a drawing of a data structure for a record for measurement history information for the instrument system as described in various representative embodiments consistent with the teachings of the invention.

## DETAILED DESCRIPTION

As shown in the drawings for purposes of illustration, the present patent document relates to novel techniques for controlling the calibration of measurement instruments. Previous methods for such control have relied upon various techniques including using centralized databases and removable stickers attached to individual instruments. If incorrectly implemented, these techniques may enable the use of out of calibration instruments for making measurements. Such a situation can result in inaccurate readings. In addition, keeping an instrument in active service with as little down time as possible for calibration is very important in modern production environments.

In the following detailed description and in the several figures of the drawings, like elements are identified with like reference numerals.

In the following a lock-out or warning method is disclosed that could be used with an instrument would be of value in preventing out of calibration instruments from being used in active service. The instrument itself or a system with which the instrument is in communication, could keep track of when the instrument had last been calibrated. In the event that an operator does wish to perform a measurement with an instrument that is out of calibration, the method can include the ability to override any lock-out or restriction that may have been imposed due to the instrument being out of calibration. Further, the operator can be informed of the likely uncertainty that will result from having performed the measurement should that measurement be taken even though the instrument is out of calibration.

In addition, representative embodiments reduce the time required to calibrate an instrument or system by tracking exactly which signal paths, subsystems, and ranges are actually being used or may potentially be used, allowing the person doing the calibration to calibrate ONLY that part of the instrument that is necessary. Additionally, these embodiments provide a safeguard against using non-calibrated signal paths, subsystems, or ranges by providing a warning if one of them is used. Advantages provided are as follows: (1) time is saved by not performing a full instrument calibration, (2) the

calibration control system is less prone to human error by not missing paths or ranges that need to be calibrated, or by not calibrating paths or ranges that will not be used, and (3) if a non-calibrated path or range is used, the user is informed of the fact that his measurement accuracy may be compromised and what the potential inaccuracy in his measurement will be if it is decided to take the measurement even though the instrument is out of calibration.

Ensuring that instruments and systems are in calibration when a measurement is made is becoming increasingly important. One of the key contributors to this efficiency is keeping the instruments and systems in an active mode.

Traditionally, a measurement instrument or system is periodically calibrated to ensure measurement accuracy. This calibration is done for the entire instrument or system (calibrating all signal paths and subsystems over their entire range of operation), and is typically quite time consuming. The instrument or system must be taken "offline" to do this calibration. If the instrument is being used in a manufacturing environment, taking it “offline” can potentially result in shutting down a part of that manufacturing process.

The application for which the instrument or system is used often utilizes only a portion of its full capability (not using some signal paths and/or subsystems, and/or not using the full range of the instrument's or system's capability), yet when the instrument is calibrated, ALL paths and ALL subsystems are calibrated, even those that are not being used, and the calibration is done over the ENTIRE range of the instrument's specified performance. This results in long calibration times (resulting in reduced efficiency of the manufacturing process while calibration is taking place).

To reduce the amount of time required for calibration, one solution is for the person doing the calibration to ask what the instrument or system is being used for, and calibrate only the paths or subsystems he feels will be used for that application, and possibly only calibrate a subset of the performance range specified for the instrument or system. While this procedure can significantly reduce calibration time, there are some distinct disadvantages to this approach: (1) the person doing the calibration may inadvertently calibrate unused signal paths, subsystems, or ranges (not harmful, but time consuming), (2) the person doing the calibration may NOT calibrate signal paths,

subsystems, or ranges that ARE being used, thereby compromising measurement integrity, and (3) the user may use the instrument or system in a different application utilizing different signal paths, subsystems and/or ranges that have not been calibrated and the user will have no way of knowing that these paths, subsystems, or ranges have not been calibrated.

Representative embodiments reduce the amount of time required to calibrate an instrument or system by tracking which signal paths, subsystems, and ranges are actually being used, allowing the operator performing the calibration to calibrate only the signal paths, subsystems, or ranges that are necessary. Additionally, it provides a safeguard against using non-calibrated signal paths, subsystems, or ranges by providing a warning if one of these is used.

Previous solutions are more prone to human error, either missing paths or ranges that need to be calibrated, or calibrating paths or ranges that are not used. Also, if a non-calibrated path or range is used, the user has no way of knowing that their measurement accuracy may be compromised. Representative embodiments disclosed herein solve these problems.

Representative embodiments provide techniques for tracking which signal paths and measurement ranges in an instrument or system are being used, and the frequency of use. This is accomplished by the master controller in the instrument or system monitoring the measurements being taken.

One method of tracking and monitoring signal paths and measurement ranges is described in the following. When the instrument or system is first calibrated (either when it is manufactured or when it is installed), an internal table of "Electronic Calibration Stickers" is updated with a variety of information for each signal path over all measurement ranges of the instrument or system, including calibration date, date next calibration is required, etc. This information is updated at each subsequent calibration or service by the calibration or service software. When a measurement is taken, the master controller determines (using an internal look-up table) which signal paths are used by the measurement and which range is going to be used. The due date for calibration for each signal path at the required range is compared with the current date. If the calibration is

still valid, the measurement proceeds, and an internal usage table (which keeps a count of how many times each signal path has been used at each range, both since last calibration and since last maintenance) is updated. This table may also keep track of when each signal path is used at each range, such as keeping a total by week or month for each signal path if the calibration is no longer valid. A warning is issued to the operator, and depending upon implementation details and configuration, the measurement may or may not be permitted to proceed.

During future calibrations, the user of the instrument or system may choose not to calibrate signal paths and ranges that have not been used or have only been used sparingly since the previous calibration, thereby reducing calibration time and associated costs.

Portions of the tracking functionality can be selectively disabled for those who do not desire it, running the gamut from full monitoring with "Electronic Calibrations Stickers" for each signal path/range combination to no monitoring with a single "Electronic Calibration Sticker" that indicates when the last full calibration was done and when the next one is due.

Figure 1 is a drawing of an instrument system **100** as described in various representative embodiments consistent with the teachings of the invention. The instrument system **100** is also referred to herein as the instrument **100**. In Figure 1, the instrument system **100** comprises a measurement module **105**, also referred to herein as measurement electronics **105**, a control module **110**, a clock **115**, a calibration memory **120** which comprises calibration information **140**, and a display **125**. A value of a parameter associated with a unit under test **130** is detected at input **106** of measurement electronics **105**. If the instrument is within its calibration cycle, i.e., it is in calibration, the measurement module **105** transposes the measured parametric value into an output signal which it can make available at data output **107**. The output signal at data output **107** is an electronic signal representative of the parametric value which may be stored in a data memory **135** as shown in Figure 1, transferred to another electronic device or system, or otherwise used. Also, if the instrument is within its calibration cycle, the measurement module **105** transposes the measured parametric value into a display signal

which it makes available to the control module **110** at display output **108**, and which the control module **110** then transfers to the display **125**.

When a measurement is made by the measurement electronics **105**, the control module **110** obtains a time from the clock **115** which it compares with calibration information **140** stored in calibration memory **120** to determine whether or not the instrument is out of calibration, i.e., the clock time is later than a calibration due time. The calibration information **140** identifies the calibration due time for the instrument system **100**. When the clock time obtained from the clock **115** is past the calibration due time obtained from the calibration information **140** stored in the calibration memory **120**, the control module **110** can prevent the measurement electronics **105** from making a measurement. This prevention can be effected in one or more of several ways. For example, the signal from the unit under test **130** can be locked out or prevented from reaching all or part of the measurement electronics **105**, the output signal at the data output **107** can be locked out or prevented from reaching the data output **107**, and/or the signal at the display output **108** can be locked out or prevented from reaching the display **125**. Further, the control module **110** can display on the display **125** a message indicating that the instrument is out of calibration. The lock out or restriction applied to the measurement electronics **105** can be overridden by input from the user **145** to the control module **110**. If the instrument system **100** is controlled by another electronic system, a message can be sent to the controlling system indicating that instrument system **100** is out of calibration.

When a measurement(s) is made, a history of that event can be stored as measurement history information **180** which is stored in a measurement history memory **170**. Control of this storage and retrieval of it is managed by the control module **110**. User input **145** is also shown in Figure 1 which could be, for example, instructions to the control module **110** to override the lock out placed on taking a measurement due to the instrument **100** being out of calibration. This user input can come from either a human user or a controlling system.

Figure 2 is a flow chart of a method **200** for controlling the calibration of the instrument **100** as described in various representative embodiments consistent with the

teachings of the invention. In Figure 2, a request is made in block **205** for the instrument **100** to make one or more measurements. This request could be in the form of a manual request by the operator, as for example pushing a button or flipping a switch on the instrument **100**. It could also be actuated by a clock (i.e., at a preselected time or time interval) or by a preselected parameter attaining a preselected level. In addition, it could be actuated by a controlling electronic system. Block **205** then transfers control to block **210**.

In block **210**, instrument determines the calibration status for the instrument **100**. This procedure has been described with respect to Figure 1. Block **210** then transfers control to block **215**.

When calibration of the instrument **100** is past due, block **215** transfers control to block **220**. Otherwise, block **215** transfers control to block **270**.

In block **220**, the instrument **100** is locked with respect to making the measurement as was described in the discussion of Figure 1. Block **220** then transfers control to block **225**.

In block **225** the user is notified that the calibration is past due by, for example, displaying a notification to that affect on the display **125** of Figure 1. In alternative embodiments, display **125** could be simply an indicator **125**, as for example an indicator light **125**. If an electronic system initiated the measurement request, a message can be sent to the controlling system that the calibration is past due. Block **225** then transfers control to block **230**.

In block **230**, the measurement uncertainty can be obtained knowing the time from the clock **115** and the calibration information **140** stored in the calibration memory **120**. Measurement uncertainty is the most likely potential error in making a measurement with the instrument **100** when the instrument **100** has been out of calibration for a given time and is operated under preselected measurement conditions, as for example making a particular type of measurement at a particular frequency using a particular range of the instrument **100**. The measurement uncertainty can be obtained from data in a table in the calibration information **140** and/or by performing a computation based on such data. Once the measurement uncertainty is obtained, block **230** transfers control to block **235**.

In block **235**, the user is informed of the measurement uncertainty should he decide to proceed with making the measurement. The notification could be sent to the display for a user-initiated measurement, or, if the measurement is initiated from an electronic system, the notification could be sent to the requesting system. Block **235** then transfers control to block **240**.

When the user decides to perform the measurement(s) in spite of the fact that the instrument **100** is out of calibration, block **240** transfers control to block **265**. Otherwise, block **240** transfers control to block **245**.

In block **245**, the instrument is removed from service. Block **245** then transfers control to block **250**.

In block **250**, the instrument is calibrated. Block **250** then transfers control to block **255**.

In block **255**, the calibration history which is a part of the calibration information **140** is updated in the calibration memory **120**. Block **255** then transfers control to block **260**.

In block **260**, the instrument **100** is unlocked with respect to performing measurement(s) and the instrument is returned to service. Block **260** then transfers control to block **205**.

In block **265**, the instrument **100** is unlocked with respect to performing measurement(s). Block **265**, then transfers control to block **280**.

When the time the calibration is due is near the clock time, block **270** transfers control to block **275**. In other words, when the instrument calibration due date is approaching, a user may be notified of that fact, wherein the notification is initiated automatically by the instrument. This proactive notification allows the user to schedule the calibration at a convenient time, thus minimizing or eliminating the cost of having the instrument out of service for calibration. Otherwise, block **270** transfers control to block **280**.

In block **275**, the instrument system **100** notifies the operator at preselected time(s) that the calibration due time is approaching. Block **275** then transfers control to block **280**.

In block **280**, the measurement(s) is performed. Block **280** then transfers control to block **285**.

In block **285**, the result of the measurement(s) in block **280** is made available at outputs **107**,**108** of the measurement module **105** as was noted in the discussion of Figure 1. Block **285** then transfers control to block **290**.

In block **290**, measurement history data in the calibration memory **120** is updated. Block **290** then transfers control to **205**.

Figure 3 is a flow chart of another method **300** for controlling the calibration of the instrument system **100** as described in various representative embodiments consistent with the teachings of the invention. In Figure 3, block **305** determines the calibration status for a signal path, a type of measurement, and/or a particular frequency or frequency range. By performing a calibration only for specific signal path(s), subsystems, types of measurements (voltage, current, etc.), and frequencies/frequency bands for which it is anticipated that the instrument **100** will be used, the time required to calibrate the instrument **100** will be reduced. Block **305** then transfers control to block **310**.

When the calibration is past due for the selected measurement conditions (signal path, subsystem, type measurement, frequency/frequency band, etc.), block **310** transfers control to block **315**. Otherwise, block **310** transfers control to block **320**.

In block **315**, the user is notified that the calibration is past due for the selected measurement conditions (signal path, subsystem, type measurement, frequency/frequency band, etc.). If the measurement is requested by an electronic system, a message could be sent to the requesting system that the calibration is past due for the selected measurement conditions. Block **315** then transfers control to block **320**.

When there are more selected measurement conditions (signal path, subsystem, type measurement, frequency/frequency band, etc.) to check, block **320** transfers control to block **325**. Otherwise, block **320** terminates the process.

In block **325**, the process increments to the next measurement condition (signal path, subsystem, type measurement, frequency/frequency band, etc.) to check. Block **325** then transfers control back to block **305**.

As will be understood by those of ordinary skill in the art, various represented

embodiments may not necessarily comprise all steps discussed above.

Figure 4 is a drawing of a data structure for a record **400** for calibration information **140** for the instrument system **100** as described in various representative embodiments consistent with the teachings of the invention. The record **400** for calibration information **140** is also referred to herein as the calibration information record **400**. In the embodiment of Figure 4, the calibration information record **400** comprises a signal path identification **405**, a type measurement **410**, a frequency range **415**, a calibration time interval **420**, and a time calibration due **425**. In another representative embodiment, a specific frequency **415** or specific frequencies **415** replaces frequency range **415**. In various embodiments, some of the components of the calibration information record **400** may not be present and in other embodiments other components may be present in the calibration information record **400**. For example, the time of last calibration could replace the time calibration due **425**.

Figure 5 is a drawing of a data structure for a record **500** for measurement history information **180** for the instrument system **100** as described in various representative embodiments consistent with the teachings of the invention. The record **500** for measurement history information **180** is also referred to herein as the measurement history record **500**. In the embodiment of Figure 5, the measurement history record **500** comprises a signal path identification **505**, a type measurement **510**, a frequency range **515**, and a time of measurement **520**. In another representative embodiment, a specific frequency **515** or specific frequencies **515** replaces frequency range **515**. In various embodiments, some of the components of the measurement history record **500** may not be present and in other embodiments other components may be present in the measurement history record **500**.

One skilled in the art will understand that there are numerous embodiments consistent with the teachings herein. In particular, representative embodiments are capable of automatically limiting use of the instrument **100** for cases in which the instrument **100** is out of calibration. This method comprises first determining the calibration status of the instrument **100**, wherein the determination is made automatically by the instrument by examining an internal instrument flag. When the calibration of the

instrument **100** is past due, the user or requesting system is notified of that fact. Such notification is initiated automatically by the instrument. At that point, the user has two choices (1) he can make the measurement anyway or (2) he can remove the instrument from measurement service. If he removes the instrument from service, the user then calibrates the instrument or has it calibrated (as many users of measurement instruments do not have the equipment or expertise to perform the calibration themselves), and the person performing the calibration updates an internal instrument flag to reflect the new calibration time. The instrument may then be returned to measurement service. Maintaining the instrument in measurement service is also an option.

Representative embodiments may further include the instrument automatically activating a restriction inhibiting the instrument from making a measurement before the user is notified that the calibration is past due. However, means for manually overriding the restriction is provided. After the calibration is performed and the internal instrument flag is updated to reflect the new calibration time, the measurement restriction is removed.

In a representative embodiment, the determination of instrument calibration status is initiated by comparison of a clock with a preselected clock time which species the calibration due time. In another representative embodiment, the determination of instrument calibration status is initiated by making a measurement.

In still another representative embodiment, after a user is notified that the calibration is past due, the measurement uncertainty is obtained, and the user is informed of the measurement uncertainty. Measurement uncertainty can be determined from numerous previous measurements by, for example, factory measurements at various times beyond the calibration due time.

The determination of instrument calibration status may comprise determining the calibration status for each of a sub-set of all measurement path of the instrument, wherein the sub-set of all measurement paths of the instrument comprises all measurement paths of the instrument, determining the calibration status for each of a sub-set of all types of measurements that the instrument can make, wherein the sub-set of all types of measurements comprises all types of measurements that the instrument can make, and/or

determining the calibration status for each of a sub-set of all frequencies or frequency ranges for which the instrument is capable of making a measurements, wherein the sub-set of all frequencies or frequency ranges for which the instrument is capable of making a measurements comprises all frequencies or frequency ranges for which the instrument is capable of making measurements.

As is the case, in many data-processing products, the instrument measurement system **100** shown in Figure 1 may be implemented as a combination of hardware and software components. Moreover, the functionality required for using the invention may be embodied in computer-readable media (such as, but not limited to, 3.5 inch floppy disks, conventional hard disks, DVD's, CD-ROM's, Flash ROM's, nonvolatile ROM, Flash RAM, other nonvolatile RAM, and RAM) to be used in programming an information-processing apparatus (e.g., an instrument) to perform in accordance with the embodiments described herein.

While the present invention has been described in detail in relation to preferred embodiments thereof, the described embodiments have been presented by way of example and not by way of limitation. It will be understood by those skilled in the art that various changes may be made in the form and details of the described embodiments resulting in equivalent embodiments that remain within the scope of the appended claims.